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EVALUATION OF SYNTHETIC AUTOMOTIVE CRANKCASE LUBRICANTS FOR MILITARY APPLICATIONS

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EVALUATION OF SYNTHETIC AUTOMOTIVE CRANKCASE LUBRICANTS FOR MILITARY APPLICATIONS

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by

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		MIL-L-21260B
		MIL-L-46167

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Army is in need of a suitable year round crankcase lubricant to eliminate the numerous oil drains *caused* by the seasonal/ambient temperature changes, and *necessitated* by the single lubricant viscosity grades employed in the combat/tactical fleet specification, MIL-L-2104C. For Army non-combat (administrative) and other government agencies, a multigraded oil is available (MIL-L-46152) which drastically reduces the need for seasonal drains in that type of service. However, the develop-

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20. ment of a *single lubricant* for *year round* combat tactical fleet *usage* has been the thrust of the Army's on-going automotive lubricants research effort for some time. Success of such a lubricant, pressed into Army arctic service as a *problem solver* in the late 1960's, provided early, but limited, confidence that synthetic lubricants might someday be used as the much needed *year round* engine oil for the combat tactical fleet. Then, the 1973 Middle East oil embargo, and the consequent advent of the so-called *long-life*, *extended-drain*, or *no-drain synthetic oils*, and there was more incentive to step up the search for the *year round single lubricant*. The current program investigated certain basic performance characteristics of nine of the *commercial* long-life synthetic lubricants and compared them with typical USAF, USN, and Army synthetic and conventional mineral based oils. Results show that several of the *commercial* long-life synthetics have additive systems very similar to Army synthetic lubricants qualified under the administrative specification MIL-L-46152, or under the Purchase Description for Army arctic operations. Several of the *commercial* long-life synthetics show oxidation, corrosion, and wear performance equal to MIL-L-46152/MIL-L-2104C mineral based lubricants or Army synthetic arctic engine oils. Some *commercial* synthetics show oxidation stability that might exceed the conventional mineral based oils, however, some of the *commercial* synthetics are lower-level performers than currently qualified conventionally formulated mineral oils. This initial testing does not suggest that an *all purpose year round* synthetic is now commercially available. Further engine test work must be conducted prior to the adoption of synthetic lubricants for across-the-board usage in the combat/tactical fleet. Recommendations for further laboratory and fleet test work are made.

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FOREWORD

The work reported herein was conducted at USAMERADCOM, and at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL) located at Southwest Research Institute, San Antonio, Texas under Contract DAAK02-73-C-0221, during the period June 1974 through September 1975. The contract monitor was Mr. F.W. Schaekel, USAMERADCOM, DRXFB-GL, Ft. Belvoir, Virginia.

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INTRODUCTION

Since November 1970, the Army has used basically two lubricant specifications to describe the performance and procurement requirements for the engine oils used in combat/tactical and administrative ground equipment. These two specifications, MIL-L-2104C[1]* and MIL-L-46152[2] respectively, serve not only the Army, but the other DOD military services and other Federal Agencies as well (i.e., GSA Interagency motor pools, Postal Service, Bureau of Reclamation, etc.). In making use of multi-viscosity-graded oils, the MIL-L-46152 specification provides lubricants for *year-round usage* in non-combat/tactical applications. Even where certain engine manufacturers permit, these multigrade oils are used in heavy-duty/high output applications in order to eliminate oil changes necessitated by single viscosity grade usage in areas of wide ambient temperature fluctuations. Therein lies a major applications problem with the MIL-L-2104C specification, whose products have *traditionally* been single viscosity grade oils. Usage of the word *traditional* is intentional here, because exclusion of multigrade oils *per se* has never been the intent of the specification; however, until recently, experience had shown that conventionally formulated (polymer-thickened mineral oil) multigrade engine lubricants either (1), could not meet all the specification requirements or (2), their use was not recommended by various engine manufacturers due to increased ring-belt deposits, increased oil consumption, and increased cylinder liner scuffing and general wear tendencies.

Conventionally formulated/polymer thickened multigrade engine oils are still not *widely used* in commercial heavy-duty diesel engines, and when used, the viscosity grade is generally SAE 20W-30 or 20W-40[3,4]. Indeed, an SAE 20W-40 engine oil extends the useful ambient temperature range and would reduce the Army's frequency of oil changes normally dictated by ambient temperature requirements--i.e., the so-called *seasonal drain requirement*. Certainly, an SAE 10W-40 would eliminate three of

*Superscript numbers in parentheses denote references at end of report.

the four single grades used in combat/tactical equipment *engines* (i.e., grades OE/HDO-10, -30, and -40), but the grade OE/HDO-50 would remain for certain air-cooled engine applications. However, it is not expected that in the near future, technology advances will yield a *conventionally formulated,* multigrade engine oil suitable for *year-round operation* in the Army combat/tactical vehicle fleet. Based on U.S. Army experience with high-output diesel engine lubricant requirements in arctic service[5,6,7], and recent European experiences[8,9], it is more likely to expect that a suitable year-round engine oil for the combat/tactical engines will be the result of a breakthrough in synthetic or hybrid lubricant formulation technology. The Army's new arctic engine oils are essentially *non-polymer thickened* synthetic-based lubricants designed for arctic service, i.e., at ambient temperatures below 40°F; however, these oils might have year-round acceptance in *some* applications outside the arctic, but certainly *not* in across the board usage. In any event there is great need in the Army, DOD, and the civilian sector for:

(1) eliminating the seasonal drain requirement
(2) extending the operational oil drain interval
(3) ultimately eliminating the oil drain at the organizational level.

Whether or not the multigrade, *year-round* engine oil is formulated with synthetic materials, there are significant benefits to the government if oil drain intervals could be extended or eliminated. These include:

(1) Improved readiness for movement between various climatic zones
(2) Reduced logistics volumes and line items
(3) Reduced maintenance time

BACKGROUND

The early history and recent technical acceleration of synthetic lubricants has been well documented[10,11]. The German experience on the Russian Front in World War II dramatically emphasized the importance of low-temperature properties for lubricants used in combat equipment. This, plus the absence of an independent petroleum source, forced German technology to devise synthetic lubricants having wider temperature capabilities than mineral oils. Post-war development of aviation gas turbine engines provided further stimulus for synthetic lubricant advances.

With the introduction of modern high-output diesel engines for tactical and combat vehicles into the U.S. Army in the early 1960's, the engine lubricant's operational environment was changed such that previously acceptable test severity limits and performance criteria were no longer meaningful. This was particularly evident in the mid-1960's when a sequence of two-cycle diesel engine failures in M551 General Sheridan and XM578 vehicles during Alaskan winter operations[12,13] demonstrated the inadequacy of conventional MIL-L-10295B sub-zero engine oils (OES)[14]. Again, the difficult requirement of low temperature fluidity coupled with good high temperature performance dictated the introduction of synthetic engine oils into the Army inventory[5,6,7,15] as *problem-solvers*. The excellent performance experienced with these synthetic arctic oils, the temporary shortage of lubricant basestocks caused by the 1973 Middle East crude oil embargo, and the consequent advent of so-called *long-life* or extended drain and *no-drain* synthetic crankcase lubricants motivated the Army to initiate an experimental program intended to define synthetic automotive lubricant performance in terms of lab-bench-engine tests originally developed either for automotive mineral oil or aviation gas turbine lubricant specifications, and field testing to confirm lubricant acceptance.

OBJECTIVE

This experimental and analytical study has not been a sequential-elimination screening program, but rather an effort to learn as much as possible about current-generation *commercial synthetic automotive crankcase lubricants* and to interpret findings in terms of Army requirements. It was desirable to determine whether--through the use of more flexible lubricants--a portion of the Army's procurement-supply-operations chain could be *simplified.*

TECHNICAL PROGRAM

Pursuant to the above goals, a selection of laboratory, bench and engine tests was initiated in parallel with an analytical program intended to characterize typical synthetic base stocks and additive packages. Since the Army's principal automotive crankcase lubricant specifications are MIL-L-46152 (commercial/administrative vehicles) and MIL-L-2104C (tactical and combat vehicles), a mineral-based lubricant qualified to both of these specifications was included for reference, as were two synthetic gas turbine lubricants qualified to the USAF MIL-L-7808G[16] and the USN MIL-L-23699B[17] specifications.

Test Lubricants

Table 1 presents physical properties and composition data for the twenty-one lubricants used in this study. The products are divided into two groups: Qualified/Candidate Military Lubricants, and Commercial Synthetic Lubricants.* The reference oils are grouped at extreme left, followed by synthetic oils, qualified to Aberdeen Proving Ground Purchase Description No. 1[7], or candidates for MIL-L-46167, the Army's new arctic engine oil specification (OEA)[15]. The arctic lubricants

*Two military lubricants (AL-3776 or AL-5075, and AL-5009) are also commercial products.

TABLE 1. PHYSICAL PROPERTIES AND COMPOSITION OF TEST LUBRICANTS

Lubricant code	AL-5711	AL-5712	AL-4591	AL-5075	AL-5140	AL-5065	AL-5096	AL-5009	AL-5680	AL-5681
	Qualified/Candidate Military Oils									
Type	Syn	Syn	Mineral	Syn	Syn	Syn	Syn	Syn	Syn	Syn
SAE vis grade	N/A	N/A	OE/HDO-30	5W-20	5W-20	5W-20	5W-20	10W-30	10W-40	10W-50
Description										
SAE J183a	N/A	N/A	SE/CD	CC	CC	CC	CD	SE/CC	SE/CC	SE/CC
Military	MIL-L-23699	MIL-L-7808G	MIL-L-46152 MIL-L-2104C	Arctic	Arctic	Arctic	Arctic	MIL-L-46152	MIL-L-46152	MIL-L-46152
Properties										
Vis at 210°F, cSt	5.06	3.59	12.71	6.15	6.52	7.46	5.81	9.94	14.78	17.39
Vis at 100°F, cSt	27.46	14.70	130.24	29.39	35.08	43.17	29.45	56.90	89.69	111.22
Viscosity index	125	148	97	180	153	155	153	178	183	178
TAN	0.33	0.22	2.38	0.22	2.04	3.58	2.49	3.08	2.59	2.76
TBN	0.05	0.05	4.77	7.77	8.04	7.49	7.97	6.93	8.60	8.32
Flash point, °F	480	430	465	471	440	465	470	421	466	465
Pour point, °F	55	< -80	5	-70	65	55	65	55	40	40
API gravity at 60°F	9.3	16.4	27.2	21.2	28.4	31.6	23.5	29.1	22.0	21.7
Composition, % wt										
Sulfur	0.03	0.02	0.39	0.05	0.17	0.53	0.35	0.27	0.26	0.25
Phosphorous	0.09	0.09	0.065	0.01	0.08	0.11	0.09	0.11	0.10	0.10
Barium	0	0	0.11	0.84	0.004	<0.001	<0.005	0.33	0.001	0.001
Calcium	0	0	0.14	0.0005	0.25	0.28	0.32	0.025	0.26	0.25
Zinc	0	0	0.08	0.001	0.09	0.11	0.11	0.10	0.11	0.11
Sodium	0	0	ND	0.0012	0.0003	0.004	<0.004	0.0006	0.01	0.01
Sulfated ash	0.01	0	0.87	1.53	0.75	1.15	1.13	1.08	1.05	1.02
Carbon residue, % wt	0	0.01	0.96	1.39	0.96	1.48	ND	1.10	1.10	1.10

Lubricant code	AL-5664	AL-5666	AL-5669	AL-5670	AL-5671	AL-5723	AL-5724	AL-5738
	Commercial "Extended-Drain" Oils							
Type	Syn	Syn	Syn	Syn	Syn	Syn	Syn	Syn
SAE vis grade	5W-20	10W-30	10W-40	10W-50	10W-40	10W-40	10W-40	10W-50
Description								
SAE J183a	SE/CD	SE/CD	SE	SE	CD	SE/CD	SE/CD	SE
Military	None	None	None	None	None	None	None	None
Properties								
Vis at 210°F, cSt	6.32	11.80	14.82	20.99	15.48	14.57	14.60	18.85
Vis at 100°F, cSt	29.91	108.64	85.28	127.06	93.93	102.4	85.20	116.00
Viscosity index	182	107	195	203	188	133	144	142
TAN	0.60	2.04	1.61	1.40	3.08	5.86	1.54	2.25
TBN	[illegible]	5.53	8.04	7.49	9.72	9.16	2.17	0.05
Flash point, °F	489	472	465	460	460	400	440	440
Pour point, °F	70	+15	50	40	45	25	31	30
API gravity at 60°F	21.0	28.3	22.1	22.2	21.4	22.6	21.9	16.4
Composition, % wt								
Sulfur	0.04	0.29	0.20	0.26	0.43	0.69	0.20	0.29
Phosphorous	0.02	0.07	0.08	[illegible]	0.10	0.12	0.08	0.11
Barium	0.92	0.12	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Calcium	0.002	0.14	0.19	0.15	0.28	0.32	0.23	0
Zinc	0.002	[illegible]	0.07	0.08	0.11	0.19	0.11	0.15
Sodium	0.002	0.003	0.001	0.0008	0.003	0.002	0.02	0.0001
Sulfated ash	1.58	0.88	0.97	0.67	1.25	1.58	0.90	[illegible]
Carbon residue, % wt	1.48	1.04	0.95	0.76	1.46	1.96	0.94	0.57

ND - Not determined
N/A - Not applicable
Syn - Synthetic

are diesters, synthesized hydrocarbons or *hybrid* blends of each which have demonstrated good performance in laboratory tests and field Army arctic operations since 1967[5,7]. The next group are synthetic-based lubricants already qualified to MIL-L-46152, and the final group is a representative collection of current-generation commercial synthetics intended for extended-drain operation in commercial fleet vehicles and private passenger cars for periods of roughly 25,000-50,000 miles[18-21]. In the current program, this latter group of lubricants are referred to as the *Commercial Extended-Drain Oils*. Note from the data in Table 1, that the additive package makeup for the commercial *extended-drain* lubricants is quite close to many of the qualified/candidate military oils (synthetic and mineral-oil based). Also, the physical properties of the commercial oils do not differ radically.

Bench Tests

Well-known standard bench tests were used in this phase of the investigation. These were:

1. *Oxidation-corrosion* per Method 5307, Federal Test Method Standard 791B[22] (48 hours at 200°C per the forthcoming USAF MIL-L-7808H).

2. *Oxidation-corrosion* per Method 5308, FTMS 791B (72 hours at 175°C, modified for special catalyst metals and heavier aeration).

3. *Friction and Wear* per ASTM D2714-68 (Faville-Levally LFW-1 machine at a selected load/speed/temperature combination of 52,000 psi max. Herz stress, 450 fpm, and 150°C).

4. *Thermal Oxidation* per modified Method 2504 FTMS 791B (TOST rig, 50 hours at 175°C).

5. *Thermal Oxidation* per modified ASTM D3241 (JFTOT, 10 hours at 370°C, recirculated charge).

6. *Corrosion Protection* per MIL-L-21260B[23], the specification for internal combustion engine preservation and break-in oils (these included Humidity Cabinet, Salt Water Immersion, and HBr Acid Neutralization).

7. *Seal Swell Test* per GM 6137-M (DEXRON II ATF) and per Ford M2C33-G; only a limited number of these tests could be conducted due to funding limitations.

A summary of these bench tests with the principal operating conditions is given in Table 2.

TABLE 2. SUMMARY OF PRINCIPAL CONDITIONS FOR BENCH TESTS

Test	*References*	*Conditions or Modifications*
Oxidation-corrosion	FTM5307	48 hr at 200°C, 10 L/hr, Ti, Mg, M-50, Bronze, Ag, Al, Fe catalysts
Oxidation-corrosion	FTM5308	72 hr at 175°C, 10 L/hr; *fritted glass air tube*; Cu, Fe, Al catalysts
Thermal oxidation	FTM 2504	Modified "TOST", 175°C, 50 hr
Thermal oxidation	ASTM D3241	Modified for lubricant deposition at 370°C, 10 hr
Rubber seal swell	GM DEXRON-II Ford M2C33-G	150°C, 70 hr 150°C, 168 hr
Friction and wear	ASTM D2714-68	LFW-1 machine at 450 ft/min; 150°C, 52000 psi
Corrosion protection	MIL-L-21260B	Humidity cabinet, salt water immersion, HBr acid neutralization

Engine Dynamometer Wear Tests

A screening wear test developed at Southwest Research Institute utilizing a 1972 Pinto 2000 cm^3 engine, operating at 3000 rpm, oil sump 104°C, and coolant 81°C, wherein irradiated cam follower wear rate is measured by continuous recording of the concentration of radioactive wear debris in the oils[24].

Other Laboratory Tests and Performance Correlations

Chemical/analytical techniques were applied in attempts to characterize some of the synthetic lubricants into broad family descriptions. This work has been highly successful and will be discussed in a separate report to be issued in the future.

In separate programs conducted earlier[25,26], certain of the synthetics (L-689, L-722, L-725, and L-807) and the mineral-based reference oil (L-738) were evaluated in 6V53T diesel engine tests. This high-output two-cycle diesel engine is used for qualification acceptance testing of arctic engine oils per APG PD-1. Also, some of the commercial synthetics will be calibration tested in the 6V53T to compare their fuel-economy effects with a mineral-based reference oil, and endurance tested in the TACOM ER-3 high output single cylinder diesel engine to ascertain their basic diesel-engine lubrication integrity.

Fleet Test

During August 1975, a two-year field program involving gasoline powered vehicles was initiated at Letterkenny Army Depot (LEAD). The program entails the evaluation of four MIL-L-46152 lubricants* each in a separate 25-vehicle fleet operated under routine post, camp and station conditions and extended-drain service. The lubricants are being monitored by used oil analysis on a monthly basis. The balance of the LEAD fleet operating under normal drain cycles will be used for comparison. Since LEAD has been operating exclusively on VV-G-001690 unleaded gasoline for the past three years-and will continue to do so--a unique opportunity is provided to evaluate the performance of both fuel and lubricant under

*The test lubricants consist of two synthetic-based oils (AL-5680 and AL-5009) and two mineral-based products. Since the selection of the mineral-based products were made after initiation of the work covered by this report, laboratory analyses and testing of these lubricants are not included at this time.

conditions which may well become standardized in future Army operations. Table 3 presents salient features of this program.

TABLE 3. ARMY NO-DRAIN LUBRICANT EVALUATION PROGRAM

Site	Letterkenny Army Depot, Pennsylvania				
Duration	2 yr (August 1975–July 1977)				
Lubricants[a]		AL-5680	AL-5009	AL-5936	AL-6095
	SAE Vis Grade	10W-40	10W-30	10W-30	10W-30
	SAE J183a	SF/CC	SF/CC	SF/CC	SE/CC
	Base Stock	Synthetic	Synthetic	Mineral	Mineral
Fuel	VV-G-001690, Special Class A Unleaded[b]				
Vehicles	Four matched fleets of 25 (5 Sedans, 10 Pickups, 10 Heavy Trucks), each fleet using one of the above lubricants on a no-drain basis. The remaining 125 gasoline-powered vehicles at Letterkenny will operate on a regular-drain basis (using AL-5936) for comparison of cost effectiveness, lubricant performance, and environmental impact.				
Analysis	2-ounce samples from each no-drain vehicle sent monthly to AFLRL to check: • Wear and additive metals concentration • Viscosity • Acidity • Dispersancy • Water content				

[a]All lubricants qualified MIL-L-46152 products.
[b]All Letterkenny spark ignition vehicles have been operated exclusively on this fuel for the past 3 yr.

Comparisons will be made to fleet test work performed in Arctic environments from 1967 to the present(5,6). The arctic program utilized tactical and combat equipment only, so such comparisons must necessarily be qualitative.

DISCUSSION OF TEST RESULTS

Certain characteristics of synthetics are known to create potential problems when brought into contact with engine or transmission materials or when placed into certain modes of operating service(10,11). For example, due to their polar properties, *some* of the ester/diester types

cause excessive elastomer seal swell, attack painted surfaces, cause foaming/aeration, or absorb excessive water. Likewise, *certain* of the synthesized hydrocarbon class of synthetics cause unacceptable seal shrinkage. Considerable information has been reported about synthetic automotive lubricants in so-called *trade journals* (i.e., references 18 through 21), but, until recently[27-35] there have been very few *unbiased publications* about the technical or economic performance of these lubricants in automotive reciprocating engines.

The current work was intended to study those problems reported for synthetics in the literature[10,11,27-35] by means of widely employed screening tests for automotive mineral and aviation synthetic lubricants. Oxidation stability, seal compatibility, wear and corrosion were considered to be of paramount importance. Test data for these factors are presented in Tables 4 through 15. Each will be discussed separately.

Oxidation/Corrosion

Lubricant durability is critical for any extended-use operation (no-drain) as is potential chemical attack on metal surfaces. Oxidation resistance and corrosive properties were measured by FTM 5307, a procedure specified for aviation gas turbine lubricants, and by FTM 5308, also a procedure specified for gas turbine lubricants, but modified to simulate automotive temperatures and catalyst metals with more stringent aeration provided by a fritted glass sparger tube. Results for these tests are found in Table 4.

Duplicate runs were made for all lubricants in FTM 5307 testing and for those select few lubricants tested by FTM 5308-principally those qualified under MIL-L-2104C, MIL-L-46152, or APG PD-1 (MIL-L-46167 candidates). The range for viscosity change was enormous, from a +462% increase for an arctic oil, AL-3776, to a -34% decrease for a synthetic MIL-L-46152 oil, AL-5681. Most of the synthetics demonstrated what is considered to be (in MIL-L-7808) *significant* metallic corrosion, i.e., greater than

TABLE 4. OXIDATION-CORROSION DATA

Qualified/Candidate Military Oils

FTM 5307, MIL-L-7808H, 48 hr at 200 C (Bronze, Ag, Al, Fe)

Lubricant Code	AL 5711[a]		AL 5712[b]		AL 4591[c]		AL 3776		AL 5075		AL 5140	
Run No.	1	2	1	2	1	2	1	2	1	2	1	2
Vis change at 100 F	23	15	4	4	92	94	462	[illegible]	176	185	75	81
Neut no. change mg KOH/g	0.54	0.49	1.99	1.82	3.44	3.08	0.75	0.7	0.90	5.81	6.85	7.62
Metal attack (weight loss > 0.2 mg/cm²)	None		None		M-50 Fe Bronze Ag		Mg		Mg		Mg Fe Bronze Ag	

Lubricant Code	AL 5065		AL 5096		AL 5009		AL 5680		AL 5681	
Run No.	1	2	1	2	1	2	1	2	1	2
Vis change at 100 F	107	147	28	35	62	83	15	15	34	34
Neut no. change mg KOH/g	7.67	8.99	9.72	9.77	4.51	6.56	7.31	7.48	7.35	6.41
Metal attack (weight loss > 0.2 mg/cm²)	Bronze Ag		Fe Bronze Ag		M-50 Fe Bronze Ag		Ag		Bronze Ag	

Modified FTM 5308, 72 hr at 175 C (Cu, Al, Fe)

Lubricant Code	AL 5711[a]		AL 5712[b]		AL 4591[c]		AL 3776		AL 5075		AL 5140	
Run No.	1	2	1	2	1	2	1	2	1	2	1	2
Vis change at 100 F					151	230			8	8		
Neut no. change mg KOH/g					21.2	21.0			0.17	0.14		
Metal attack (weight loss > 0.2 mg/cm²)					Cu				None			

Lubricant Code	AL 5065		AL 5096		AL 5009		AL 5680		AL 5681	
Run No.	1	2	1	2	1	2	1	2	1	2
Vis change at 100 F					d	d	4	8		
Neut no. change mg KOH/g					20.4	15.2	17.4	[illegible]		
Metal attack (weight loss > 0.2 mg/cm²)					Cu		Cu			

Commercial "Extended-Drain" Oils

FTM 5307, MIL-L-7808H, 48 hr at 200 C (Bronze, Ag, Al, Fe)

Lubricant Code	AL 5664		AL 5656		AL 5669		AL 5670		AL 5671		AL 5723		AL 5724		AL 5738	
Run No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Vis change at 100 F	38	101	81	81	11	12	10	10	8	10	302	369	2	4	62	64
Neut no. change mg KOH/g	1.74	1.89	4.17	3.06	12.48	13.76	5.96	5.96	8.21	8.67	4.56	5.00	4.87	4.87	2.83	2.88
Metal attack (weight loss > 0.2 mg/cm²)	Mg		M-50 Fe Bronze Ag		Mg Bronze Ag		Fe Bronze Ag		Fe Bronze Ag		M-50 Mg Fe Bronze Ag		Bronze Ag		Mg Fe Bronze Ag	

Modified FTM 5308, 72 hr at 175 C (Cu, Al, Fe)

Lubricant Code	AL 5664		AL 5656		AL 5669		AL 5670		AL 5671		AL 5723		AL 5724		AL 5738	
Run No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Vis change at 100 F													0.2	0.3		
Neut no. change mg KOH/g													[illegible]	[illegible]		
Metal attack (weight loss > 0.2 mg/cm²)													Cu			

[a] MIL-L-23699B QP
[b] MIL-L-7808G QP
[c] MIL-L-46152/MIL-L-2104C Dual QP
[d] Solidified

0.2 mg/cm^2 coupon weight loss. This may be due to excessive concentrations of additive components put in to extend oxidation resistance.

The limited modified FTM 5308 testing was done in an effort to more sensitively differentiate between select oils. The lower temperature and longer time period (as compared to FTM 5307) did serve to demonstrate a much higher *percent* viscosity increase for the reference mineral oil, AL-5491, than for two non-related synthetics, AL-5680 and AL-5724. The solidification of AL-5009 was interesting in view of the fact that this oil is a MIL-L-46152 qualified 10W-30 synthetic furnished by the same manufacturer which produces AL-5140, an arctic engine oil (OEA) which is an analogous formulation of lower viscosity. The other synthetic Army arctic oil, AL-5075 (i.e., same as AL-3776), hardly changed in viscosity.

Thermal Oxidation Stability

The well-known Thermal Oxidation Stability Test (TOST) gear rig was employed for a second oxidation study. This appartus is normally used to evaluate gear oils under MIL-L-2105B in accordance with Method 2504, FTMS 791B, using a 50-hour test at 163°C. Temperature was increased to 175°C for this study, with the principal post-test measurements of viscosity increase and Pentane/Benzene insolubles as shown in Table 5. As with the oxidation-corrosion testing (above), the reference mineral oil, AL-4591, and the one MIL-L-46152 synthetic oil, AL-5009, showed dramatic degradation while the arctic synthetic, AL-5075, again performed well as did the MIL-L-46152 synthetics, AL-5680 and AL-5681.

TABLE 5. TOST TEST RESULTS (MODIFIED FTM2504, 50 HR AT 175°C)

	Viscosity, cSt		Viscosity Change, %		Insolubles, wt %[a]	
Lubricant	100°F	210°F	100°F	210°F	Pentane	Benzene
AL-4591	TVTM[b]	TVTM	TVTM	TVTM	15.75	5.66
AL-5009	TVTM	119.0	TVTM	1098.0	12.64	0.14
AL-5075	33.9	6.9	15.4	12.2	0.07	0.04
AL-5680	160.4	17.4	78.8	17.7	5.59	0.04
AL-5681	80.7	11.5	27.4	33.9	0.37	0.24
AL-5724	89.5	14.8	5.05	1.4	0.02	0.01

[a] Method B, with coagulant.
[b] TVTM = Too viscous to measure

The three MIL-L-46152 synthetic oils (AL-5724, AL-5780, and AL-5009) and one qualified MIL-L-46152 mineral-based oil were subjected to an experimental bench thermal oxidation stability evaluation in order to check method feasibility and to further explore this basic parameter. An ALCOR, Inc., jet fuel thermal oxidation tester (JFTOT [ASTM D3241]) was modified to a recirculatory system at atmospheric pressure and deposit-forming tendencies were evaluated in a 10-hour test procedure. Test details and results are shown in Table 6 where the ranking of the four oils is given. Note the good separation in deposit data and that the mineral-based lubricant ranks above the one synthetic and *just under* the number 2 ranking oil.

TABLE 6. THERMAL OXIDATION PERFORMANCE IN MODIFIED JET FUEL THERMAL OXIDATION TEST[a]

Rank	Base Stock	Oil Code	Deposit Character
1	Synthetic	AL-5724	30% Clean 40% Light varnish 30% Medium varnish
2	Synthetic	AL-5680	20% Clean 40% Light varnish 40% Medium varnish
3	Conventional Mineral Oil	MIL-L-46152 10W-30 Qualified product	20% Clean 20% Light varnish 20% Medium varnish 40% Medium black crinkled carbon
4	Synthetic	AL-5009	10% Clean 10% Medium varnish 80% Smooth black carbon

[a]ASTM D3241, JFTOT was modified as follows

- Maximum heater tube temperature 700° F
- Total oil volume 100 mℓ
- Oil flow rate 3 mℓ/min
- Air injection 10 mℓ/min
- Total test time 10 hr
- Oil system pressure Atmospheric

Corrosion Protection

Three corrosion-preventative tests currently employed in qualification acceptance testing for MIL-L-21260B[(23)] oils were conducted on all the

oils used in this program. The three tests are listed below and described in the respective paragraphs of the MIL-L-21260B specification:

- Humidity Cabinet Corrosion-Protection Test - Para. 4.6.1.
- Salt Water Immersion Corrosion Protection Test - Para. 4.6.2.
- HBr Acid Neutralization Corrosion Protection Test - Para. 4.6.3.

Results for these tests are given in Table 7, and summarized in Table 8. It is seen that none of the lubricants passed the HBr Acid Neutralization Test which had been anticipated. This performance requirement is unique to operational preservative oils designed for spark-ignition engine systems. However, it is interesting to note that some of the synthetic engine oils did actually pass the 30-day Humidity Cabinet Test requirement which would indicate potential rust protection characteristics of the particular product. The reference mineral-based oil (AL-4591) and some of the synthetics also passed the salt water immersion test indicative of corrosion protection in that environment.

TABLE 7. MIL-L-21260B CORROSION-PREVENTIVE TEST RESULTS

Sample Number	Humidity Corrosion Protection	Salt Water Immersion Corrosion Protection	HBr Acid Neutralization Protection
	Description	Description	Description
AL-4591	Light corrosion after 13 days	No rust or staining	Very light staining
AL-5009	Moderate corrosion after 7 hr	Moderate staining both sides	Moderate to heavy staining
AL-5068	No corrosion after 30 days	Two rust spots	Moderate staining and corrosion
AL-5078	Moderate corrosion after 9 days	Moderate staining both sides	Moderate staining
AL-5096	No corrosion after 30 days	No rust or staining	Light corrosion
AL-5140	Light corrosion after 13 days	Light staining both sides	Heavy staining
AL-5664	Stain corrosion after 2 days	Moderate staining both sides	Moderate corrosion
AL-5666	Light corrosion after 2 days	Light staining and rust spots	Heavy corrosion
AL-5669	Light corrosion after 8 days	Moderate staining both sides	Moderate corrosion
AL-5670	Light corrosion after 22 hr	Light staining	Heavy corrosion and staining
AL-5671	No corrosion after 30 days	No rust or staining	Moderate staining
AL-5680	Moderate corrosion after 20 hr	Light staining	Moderate corrosion
AL-5681	No corrosion after 30 days	Moderate staining and rust spots	Moderate staining
AL-5711	Heavy corrosion after 20 hr	Light staining	Light staining
AL-5712	Heavy corrosion after 20 hr	Light staining	Light staining
AL-5723	No corrosion after 30 days	Rust spots	Moderate corrosion
AL-5724	Moderate corrosion after 2 day	Light staining	Light corrosion
AL-5738	Heavy corrosion after 2 days	Moderate staining and rust spots	Light corrosion

TABLE 8. SUMMARIZED RESULTS FOR MIL-L-21260B CORROSION-PREVENTIVE TESTS

Sample Number	Test Results On: Humidity Cabinet	Salt Water Immersion	HBr Acid Neutralization
AL-4591	Fail	Pass	Fail
AL-5009	Fail	Fail	Fail
AL-5065	Pass	Pass	Fail
AL-5075	Fail	Fail	Fail
AL-5096	Pass	Pass	Fail
AL-5140	Fail	Pass	Fail
AL-5664	Fail	Fail	Fail
AL-5666	Fail	Fail	Fail
AL-5669	Fail	Fail	Fail
AL-5670	Fail	Pass	Fail
AL-5671	Pass	Pass	Fail
AL-5680	Fail	Pass	Fail
AL-5681	Pass	Fail	Fail
AL-5711	Fail	Pass	Fail
AL-5712	Fail	Pass	Fail
AL-5723	Pass	Fail	Fail
AL-5724	Fail	Pass	Fail
AL-5738	Fail	Fail	Fail

Elastomer Seal Compatibility

Since it was not feasible at this time to check elastomer seal compatibility of all the *commercial extended-drain* lubricants, one qualified synthetic ester-based lubricant was selected (AL-5680) for testing using Buna-N rubber and three seal materials used in MIL-STANDARD generator-set engines (believed to be polyacrylate elastomer). Compatibility with these seal materials was checked in accordance with the General Motors DEXRON II and Ford M2C33-G procedures[36,37] and the results are found in Table 9. Note that this synthetic lubricant appears to cause excessive swell with both the GM and Ford materials, and also causes excessive swell of the three O-ring samples. These results can be compared with the results in Table 10 obtained earlier[34], in which four of the synthetic arctic engine oils (the two APG PD-1 products, AL-5075 and AL-5140, and the two MIL-L-46167 candidates, AL-5065 and AL-5096) and one qualified MIL-L-46152 synthetic oil (AL-5009) were tested. In these tables, the results are also shown for a qualified MIL-L-2104C OE/HDO-10 and a MIL-L-10295B (sub-zero engine oil, OES), each *conventional mineral-based* oils. All lubricants were tested in accordance with the GM DEXRON

TABLE 9. ELASTOMER SEAL COMPATIBILITY OF SYNTHETIC LUBRICANT AL-5680-L

Test Procedure	Automatic Transmission Fluid Qualification Rubber		O-Rings From Mil-Standard Generator-Set Engines		
DEXRON-II	DEXRON-II BUNA N	M2C33-G RDR-008 BUNA N	Small Ring	Medium Ring	Large Ring
% Volume change	+7.43		+18.65	+12.01	+13.91
Points hardness change	4		2	1	2
Bend test	Not applicable		No cracks	No cracks	No cracks
Deterioration	None		None	None	None
Decomposition	None		None	None	None
M2C33-G					
% Volume change		+8.31	+19.16	+12.76	+19.19
Points hardness change		1	2	1	2
Bend test		No cracks	No cracks	No cracks	No cracks
Deterioration		None	None	None	None
Decomposition		None	None	None	None

Test Limits	Procedure: DEXRON-II[a]	Procedure: M2C33-G
% Volume change	0.40 to +4.25	+1 to +8
Points hardness change	0 to -5	-10 to +10
Bend test	Not applicable	No cracking

[a]Rubber batch 475 S

TABLE 10. GM DEXRON AND FORD M2C33-G SEAL COMPATIBILITY TEST RESULTS

Property	Specification Requirements	Oil Code Grade: Reference MIL-L-2104C OE HDO-10	Reference MIL-L-10295B OES	AL-5065 5W-20	AL-5075 5W-20	AL-5096 5W-20	AL-5140 5W-20	AL-5009 10W-30
GM DEXRON								
Dip cycle (BUNA N)								
% Volume change	0 to +5	+3.71	+8.37	+3.55	+3.08	+2.94	+4.29	+4.06
Points hardness change	0 to -10	5	4	3	5	2	3	2
Dip cycle (Polyacrylate)								
% Volume change	0 to +10	1.02	+14.25	+2.72	+15.08	+11.62	+7.72	+1.64
Points hardness change	0 to +5	0	9	+2	+8	4	4	+1
Immersion (Silicone)								
70 hr								
% Volume change	+1 to +5	1.54	+9.70	+1.03	+13.71	+5.31	+2.44	+0.93
Hardness change	0 to -5	0	5	2	4	2	1	0
140 hr								
% Volume change	--	4.05	+9.44	+1.22	+12.31	+5.06	+2.44	1.81
Hardness change	--	0	4	1	6	2	1	2
Ford M2C33-G								
Compound 1 (BUNA N)								
% Volume change	+1 to +8	1.21	+9.25	+1.44	+2.95	+11.00	+2.44	+1.36
Points hardness	+10	0	6	+3	+5	+8	+3	+2
Cracking	No	No	No	No	No	Yes	No	No
Compound 2 (Polyacrylate)								
% Volume change	+1 to +11	+4.12	+17.00	+10.12	+24.87	+14.21	+8.97	+7.63
Points hardness	+10	3	9	3	3	3	4	+3
Cracking	No	No	No	No	No	No	No	No
Compound 3 (Silicone)								
Reversion	No	No	No	No	No	No	No	No

Specification[38] tip cycle, dip cycle, and total immersion (extended to 140 hours) and the Ford seal compatibility tests. Note that in a few instances the synthetic oils exceed the specification requirements, but in general, their performance compares favorably with the two mineral-based reference oils.

Friction and Wear

Coefficient of friction and wear track width were measured using an LFW-1 machine (pin-on-desk) at a relatively severe load-speed-temperature condition (52,000 psi, 450 fpm, 150°C). "ALPHA" specimens were used: block was SAE 01 tool steel (R60C and 5 rms), while ring was SAE 4620 carburized steel (R60C and 10 rms). These bench test measurements were followed by an engine test evaluation of selected oils. This test, developed at the Southwest Research Institute[24], employs a 1972-86-hp Ford Pinto engine of 2000 cm^3 displacement whose cam followers have been irradiated. Continuous measurement of radioactive wear debris in the oil is made with a scintillation detector. Test conditions were: 3000 rpm, 104°C oil sump and 81°C coolant temperatures.

While both bench and engine tests showed relative differences between some lubricants, as shown in Table 11, only correlation studies with full-scale engine or vehicle field test will reveal whether these differences are significant. The similarity in additive packages for most of these oils may account for roughly equivalent friction and/or wear performance. In any event, there were no indications that catastrophic or otherwise unacceptable valve train wear rates would result from the use of these synthetic lubricants. [This is not to say that significant wear could not result during *actual field* operating conditions as observed in Ref. 33, but not seen in the field work reported in Ref. 32.]

Full-Scale Engine and Vehicle Testing

A comprehensive engine-dynamometer study was designed and testing was initiated using the high-output TACOM FR-3 single cylinder diesel

TABLE 11. BENCH AND ENGINE WEAR TEST DATA

Qualified/Candidate Military Oils

Lubricant Code	AL-5711[a]		AL-5712[b]		AL-4591[c]		AL-3776		AL-5075		AL-5140		AL-5065		AL-5096		AL-5009		AL-5680		AL-5681	
Run No	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Bench Test Wear (ASTM D2714-68, LFW-1 machine)																						
Wear scar width, mm	1.10	1.38	1.07	0.88	1.23	0.92	—	—	3.75	2.00	1.03	1.17	0.92	0.83	0.95	0.97	1.03	1.28	1.20	1.05	1.10	1.00
Coefficient of friction	0.05	0.05	0.04	0.05	0.07	0.06	—	—	0.09	0.06	0.06	0.07	0.07	0.07	0.07	0.05	0.07	0.07	0.06	0.07	0.06	0.07
Radioactive Tracer Wear (SwRI Pinto engine, irradiated cam followers)																						
Cam follower wear, cpm/hr	—	—	—	—	330	242	—	—	324	329	300	338	—	—	—	—	398	492	435	299	245	357

Commercial "Extended-Drain" Oils

Lubricant Code	AL-5664		AL-5666		AL-5669		AL-5670		AL-5671		AL-5723		AL-5724		AL-5738	
Run No	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Bench Test Wear (ASTM D2714-68, LFW-1 machine)																
Wear scar width, mm	2.40	1.75	0.67	0.72	0.88	0.90	0.58	1.38	0.77	1.23	1.17	1.00	0.65	1.00	1.05	1.32
Coefficient of friction	0.12	0.06	0.07	0.08	0.06	0.09	0.07	0.09	0.05	0.07	0.08	0.04	0.07	0.08	0.03	0.04
Radioactive Tracer Wear (SwRI Pinto engine, irradiated cam followers)																
Cam follower wear, cpm/hr	—	—	—	—	372	378	278	339	493	501	—	—	271	276	329	334

[a] MIL-L-23699B QP.
[b] MIL-L-7808G QP.
[c] MIL-L-46152/MIL-L-2104C Dual QP.

engine. In this study, several of the synthetic oils are being evaluated to ascertain fuel economy and basic engine endurance potentials compared with the vast amount of engine data already generated with the field proven APG-PD-1 arctic synthetics and selected MIL-L-2104C grades OE/HDO-10 and 30, conventional mineral oil-based products. This work was interrupted due to non-lubricant-related problems, and will be reported in a later interim report. However, in developing the MIL-L-46167 OEA specification, three of the synthetic arctic oils (AL-3776, AL-5140, and AL-5065) produced acceptable performance in the 6V53T qualification test (Method 354, FTMS 791B[39], the results of which are summarized in Table 12. Performance of a fourth synthetic lubricant (AL-5096) was judged a failure because it produced hot stuck rings and heavy amounts of ring face burning. Results for the conventionally formulated mineral-base reference oils are also provided in this table (i.e., oil code "I" is the OE-10 low-level or failing reference, and oil code "J" is the OE-30 high-level reference). For more detail on the performance of the arctic synthetic lubricants in the high-output two-cycle 6V53T and 8V71T diesel engines, the reader is referred to references 5, 6, and 25.

Several of the MIL-L-46152 products have been compared with the mineral-based reference oil (AL-4591) in the sequence IIIC test procedure[40]. These comparisons indicate that the synthetic materials provide better oxidation/thickening performance (lower viscosity increases) over the reference oil. It should be noted that this is a comparison with only one, single graded lubricant and may vary widely when other products (both synthetic and mineral based) are considered.

As a preliminary step prior to the above described fleet test at Letterkenny Army Depot, a single 1/4-ton pickup truck used in utility functions at AFLRL was operated with one commercial synthetic (AL-5670) under no-drain conditions November 1974 through December 1975. The vehicle has performed satisfactorily and *no makeup oil has been required,*

TABLE 12. REFERENCE & ARCTIC ENGINE OIL (OEA) PERFORMANCE IN METHOD 354 6V53T EVALUATIONS

	Target										
Test Information											
Test no		1	2	3	4	5	6	7	8	9	10
Lubricant code		AL-5140	I††	AL-5140	AL-3776	AL-5065	J‡‡	AL-5065	J	AL-5096	J
SAE Vis. Grade		5W-20	OE-10	5W-20	5W-20	5W-20	OE-30	5W-20	OE-30	5W-20	OE-30
Test hours		100	4	98	100	100	100	100	100	100	100
New Oil Analyses											
Vis., 100°F, cSt		35.54	37.26	Same as Test No. 1	28.78	43.7	115.8	Same as Test No. 5	Same as Test No. 6	30.0	Same as Test No. 6
Vis., 210°F, cSt		6.62	5.80		5.94	7.48	11.80			5.93	
TAN		1.85	1.82		0.41	1.56	1.56			2.32	
TBN		7.18	3.82		7.51	5.78	4.24			7.76	
Sulfated ash, % wt		0.88	1.05		1.62	1.19	1.04			1.19	
Flash, COC, °F		425	430		475	455	495			440	
Pour point, °F		55	15		85	55	+1			90	
Used Oil Analyses											
Final drain hr		100	4	98*	100	100	100	100	100	100	100
Vis., 100°F, cSt		33.68	38.57	34.2	29.87	48.9	121.9	49.00	120.9	32.2	107.1
Vis., 210°F, cSt		6.17	5.93	6.18	6.32	8.18	12.25	8.08	12.18	6.19	11.77
TAN		2.55	2.21	3.63	0.59	4.02	1.70	4.32	2.34	3.01	2.93
TBN		2.07	1.48	1.74	2.47	2.36	1.04	2.42	3.13	6.71	2.46
Sulfated ash, % wt		1.08	1.13	1.05	1.69	1.43	1.14	1.43	1.15	1.37	1.12
Flash, COC, °F		445	420	445	485	455	490	445	488	455	465
Engine Performance	**Target**										
Hot or cold stuck or	None	1 CS	1 HS			1 HS	2 CS	4 CS	1 CS	3 HS	2 CS
sluggish rings	HS	2 SL	2 CS	2 CS	None†	4 CS	2 SL	1 SL	1 SL	2 CS	1 P
% Ring travel scuffing											
Average of 6	< 25	27	20	46	27	17	12	9	9	27	8
Individual maximum	< 60	45	55	80	60	57	15	18	12	40	15
Piston skirt scoring	None	None	1	None	None	None	None	None	None	None	None
Piston skirt scuffing	LT‡	3 HVY 3 LT	1 HVY 4 LT	3 MED 3 LT	2 MED 4 LT	LT	LT	LT	LT	4 LT 2 MED	LT
Ring face burning	MIN**	MIN	1 HVY 5 MIN	4 HVY 2 MIN	3 HVY 3 MIN	1 HVY 5 MIN	MIN	1 HVY 5 MIN	MIN	4 HVY 1 MED, 1 LT	MIN
Avg oil consumption	< 0.75 lb/hr	0.48	3.6	0.41	0.46	0.59	0.64	0.43	0.47	0.45	0.49

*Terminated at 98 hr when crankcase pressure exceeded limit
†1 Broken F/R
‡<30% scuffed
**< 30% Burn
HS = Hot Stuck
LT = Light
CS = Cold Stuck
SL = Sluggish
P = Pinched
MED = Medium
HVY = Heavy
MIN = Minimal

††Code I MIL-L-2104B, OE-10 Reference
‡‡Code J MIL-L-2104B, OE-30 Reference

nor has there been any evidence of seal leakage or lubricant-related problems. This vehicle has accumulated 3700 miles as shown in Table 13,

TABLE 13. PICKUP TRUCK TEST ON COMMERCIAL SYNTHETIC LUBRICANT

Vehicle type	1963 Ford F-100, 1/2T Pickup truck
Lubricant code	AL-5670 Cml Synthetic "SE"
Begin test	1 November 1974
End test	Still running (20 December 1975)
Mileage	3700
Operating mode	Post-Camp-Station
Total oil added	None
Oil leakage	None noted
Maintenance	Routine only
Performance deficiencies	None observed to date

and it will continue on test indefinitely, or until problems arise. In addition, two M-151 1/4-ton (Military Utility Tactical Truck, MUTT) vehicles were operated over a four-month period at AFLRL to gain additional experience with two of the synthetics (AL-5140 and AL-5670). The summary of these tests is given in Table 14 in which the test operating details are described, and the lubricant analyses are presented. Both of the MUTT's operated essentially at idle speed, a condition not uncommon for these vehicles. Since this operation included the winter months, it was of primary interest to observe the lubricant's performance mainly for fuel dilution, viscosity change, water content, and acid number increase, which often suggests hydrolysis in certain classes of synthetics. In approximately 100 hours of engine idling over a four to five month period, no performance deficiencies were noted.

Additional Test Work and Analytical Studies

As indicated earlier, basic diesel engine testing using the TACOM ER-3 engine has been initiated. It is expected that spark ignition (SI) engine performance will also be studied using the L-141 engine from the M151 MUTT. The SI engine work is expected to begin in early FY77. Also, the field test at Letterkenny Army Depot will continue as described earlier, and later reports on synthetic lubricant performance will include detailed observations from that test.

TABLE 14. M151 VEHICLE IDLING TESTS USING TWO SYNTHETIC LUBRICANTS

	AL-5140 (APG PD-1, OEA)		AL-5670 Cml Synthetic "SE"	
Vehicle no.	USA 02FZ2570		USA 02FY3270	
Fuel	Unleaded gasoline		Normally leaded gasoline	
Begin test	21 November 1974		1 November 1974	
End test	20 March 1975		25 March 1975	
Operating conditions	Idle speed, no load, 1 hr/day for 76 days; 5 days idle at 6 hr/day		433 miles stop and go service in first 8 days; idle speed 1 hr/day, 86 days	
Total engine idle hours	106		86	
Average coolant temperature at shutdown, °F	159°		163°	
Oil pressure				
at startup, avg psi	35		29	
after 1-hr run, avg psi	30		32	
Ambient temperature range, °F	Low 37° –High 78°		Low 37° –High 78°	
Total oil added	None		3.5 qt	
Oil level at end of test	< 1 qt low		Full	
Oil leakage	None noted		None noted	
Oil Analyses	**New Oil**	**Final Drain**	**New Oil**	**Final Drain**
K. vis at 100°F, cSt	35.08	32.22	127.06	106.1
K. vis at 210°F, cSt	6.52	5.91	20.99	17.4
Total acid no.	2.04	1.96	1.40	3.2
Total base no.	8.04	7.69	7.49	5.4
Pentane insol (w/c), %	Nil	0.06	Nil	0.16
Benzene insol (w/c), %	Nil	0.04	Nil	0.06
Carbon residue, %	0.96	1.14	0.76	1.48
Water content (K.F.), %	ND	0.46	ND	0.16
Gasoline fuel dilution, %	ND	1.60	ND	0.04

ND = Not determined.

As an integral part of the Army's overall power train lubrication research effort, analytical/instrumental methods are being developed for use in determining compositional characteristics of new lubricants and to detect unusual contaminants in *new* and *used* fielded lubricants. Included among the various types of instruments being used in this work are: gas chromatography (GC), liquid chromatography (LC, HPLC, GPC) and spectrophotometry (IR, UV, AA, XRF). Methods to separate lubricants into component parts according to chemical types in order to simplify the subsequent analysis and identification of the component parts have been applied with favorable results. Technology has progressed to where it is now possible to qualitatively analyze and quantify the major base stock components in hybrid lubricant blends, i.e., those in which synthetic hydrocarbons, esters or diesters, and mineral oil-based components are blended together. For example, the synthetic hydrocarbon and alkyl diester portions of several hybrid synthetic lubricants have been separated and analyzed by infrared spectroscopy, gas chromatography, and gel permeation chromatography. The ester fractions are large and pure enough to permit further study by hydrolysis and derivatization to determine exact composition of the acidic and alcoholic components. Ultimate refinements of this approach will provide the detailed compositional information needed to define base stock characterization, correlation of component type to performance, and identification of source of *new, used, synthetic* and *re-refined lubricants,* power train and hydraulic fluids. Due to the extent and complex nature of this subject, the base stock characterization studies will be reported in a separate interim report to be issued in the future.

Four samples of one of the commercial synthetics were obtained from four different locations and inspected to determine if there were any variations in the physical and chemical properties among the samples. Results are given in Table 15, and it is noted that there are *significant differences in viscosity, sulfur, chlorine,* and *phosphorous* values. Otherwise, the four samples are quite close in the balance of the inspection properties. However, the viscosity differences indicate that the first two oils (AL-5670 and AL-5853) are SAE grade 10W-50, while the

TABLE 15. ANALYSES OF "SAME" SYNTHETIC LUBRICANT COMMERICAL "SE" - GASOLINE ENGINE OIL AND MILITARY 5W-20 OIL

Inspection Property	Commercial Synthetic Sample Number				Military Synthetic Sample Number	
	1 (AL-5670)	2 (AL-5853)	3 (AL-5854)	4 Field	1 (AL-3776)	2 (AL-5075)
API gravity	22.2	22.2	22.1	22.1	21.1	21.2
K. Vis at 100° F, cSt	127.06	124.77	92.99	94.33	28.64	29.39
K. Vis at 210° F, cSt	20.99	20.44	15.58	15.70	6.13	6.15
V.I.	203	205	192	189	214	180
TAN	1.40	1.48	1.60	1.79	0.05	0.22
TBN	7.49	7.37	7.77	6.93	6.40	7.77
Flash point, °F	460	455	470	395	480	471
Pour point, °F	-40	-45	-50	-45	-85	-70
Carbon residue	0.76	0.74	0.76	0.76	1.56	1.39
Sulfur, % wt	0.26	0.35	0.33	0.33	0.03	0.05
Chlorine, % wt	ND[a]	0.09	0.10	ND	ND	ND
Sulfated ash, % wt	0.67	0.66	0.68	0.65	1.53	1.53
Sodium, ppm	8	17	15	8	ND	ND
Calcium, % wt	0.15	0.16	0.16	0.14	0.001	0.0005
Barium, ppm	<10	<5	<5	<10	0.88	0.84
Zinc, % wt	0.08	0.09	0.09	0.08	0.001	0.001
Phosphorous, % wt	0.07	0.076	0.082	0.074	0.012	0.01

[a]ND - None detected.

second two oils (AL-5854 and "Field Sample") are SAE grade 10W-40. Since the container for each sample did not indicate the viscosity grade, it is apparent that two different SAE multi-grade ranges are being made available under the same brand name. It is also noted that these four oils, which are intended for API service SE, are quite different in additive composition compared with this supplier's other product (AL-5671), which is offered for diesel service, API CD. In a similar manner, two different samples of one of the Army synthetic oils were analyzed and these results are also shown in Table 15. It is noted that there is a 0.04 wt% difference in barium content which is well within tolerance for this analysis. Otherwise, the remaining analyses show that there is only a minimal batch to batch variation for this lubricant.

CONCLUSIONS

The following conclusions are based upon this present study plus the works referenced throughout this report:

(1) Additive package makeup for the several commercial *extended-drain* synthetic lubricants is quite close to that for many of the qualified/candidate military oils (including the mineral-oil based and synthetic types).

(2) Physical properties of the commercial synthetic lubricants do not differ radically.

(3) Several of the synthetic lubricants show bench test oxidation, corrosion, and wear performance at least equal to high-performance, qualified MIL-L-46152/MIL-L-2104C mineral oil lubricants, and APG-PD-1 (or MIL-L-46167 candidate) synthetic arctic engine oils. A few of the synthetics show oxidation resistance which promises to far surpass that of mineral oils in an automotive crankcase environment.

(4) There is indication of an elastomer seal compatibility problem between *certain synthetic oils* and Buna-N and Polyacrylate minerals. However, it would seem that this could be corrected through formulation adjustments.

(5) A synthetic-based automotive-type engine lubricant is *NOT* recommended at this time for across the board usage in Army tactical/combat vehicle/equipment engines. More test work is required prior to the recommendation for use of such materials.

RECOMMENDATIONS

1. A comprehensive *full-scale* engine-dynamometer program should be undertaken to isolate and quantitatively identify lubrication problems that might be associated with synthetic oils (valve train wear, seal compatibility, deposit control, etc.).

2. Operational fleet evaluation of synthetic oils should be expanded to include Army tactical and combat equipment.

3. The above two programs should be coordinated in such a way as to define accurate Army-wide projections for synthetics cost effectiveness and energy effectiveness.

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